Contaminated Sediments in the Elbe Basin and its Tributary Mulde

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Abstract. Data from the Elbe River and its tributaries indicate, despite extensive improvement in water quality since reunification, that the sediment situation of many priority pollutants has not reached an acceptable level. The risks for downstream sites, especially the port of Hamburg, the lower part of the tidal river Elbe and the North Sea will persist in future. In practice, the catchment-wide assessment of contaminated soil and sediment should be identified and valued for acquiring a management plan for the EC Water Framework. The focus will be the on the tributary Mulde.

Introduction

The pollution of the Elbe River and especially the catchment area of the tributary Mulde with rising groundwater-level in the mining areas and tailings of the old mining in the Ore Mountains is one of the great environmental problems of the Elbe catchment. In Saxony, the draining water from nearly all of the uranium mining sites flow into the Mulde River. In July 1998 the conference of the Elbe River responsible ministers decided to develop a strategy concept to improve the Elbe water quality, reducing the impacts of uranium mining on the Elbe River. Main objective is to get a good ecological condition of the Elbe catchment according to the EC Water Framework Directive (EC-WFD). Important steps in the improvement of the water quality of the Elbe river were done since 1998.

Nevertheless the sediments are sinks for ongoing releases from many contaminant sources; these include wet and dry fallout from air emissions, runoff from farms, solid and dissolved inputs from mines, discharges from landfills, industrial plants, and sewage-treatment plants. Even if water quality improves, sediment and floodplain soil contamination will remain a 'legacy of the past'.

Risk due to erosion of contaminated sediments and their potential impacts downstream is not covered by existing regulations. Existing regulations focus on local impacts of the relocation of contaminated sediments and do not take the whole catchment into account. On the other hand, the EC-WFD, which focuses on the catchment scale, does not explicitly mention sediments nor sediment quality and quantity. However, the strategies against chemical pollution of surface waters (EC-WFD article 16), i.e. implementation of monitoring programs until 2006 and establishment of the program of measures until 2009, have to consider sediment quality at the catchment scale.

The Elbe River is one of the major rivers in the western Europe. From its spring in the Giant Mountains (Czech Republic) to its mouth at the North Sea near Cuxhaven (Germany) it covers a distance of 1091 kilometres and a catchment area of 148.268 km^2 (see Fig. 1).

Within this region of interest, the Mulde rivers (Zwickauer Mulde, Freiberger Mulde, and United Mulde) form an important contribution to the contamination of the Elbe river (Beuge et al. 1999). The river basin of Mulde with encloses 7400 km^2 including the heavily populated industrial region Chemnitz, Zwickau and the former chemical industry centre Bitterfeld as well as the mining and metallurgy centre around Freiberg (see Fig. 2). In some of the former mining areas the re-charge of groundwater in the groundwater depression cones are still not completed (Schneider et al 2003b).

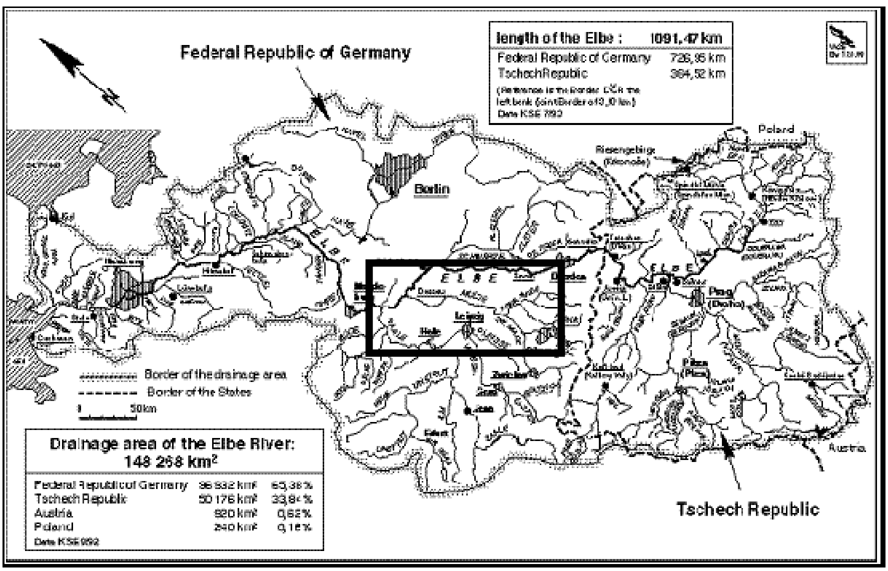

Fig. 1. Drainage area of the Elbe river and its Tributary Mulde (black marked).

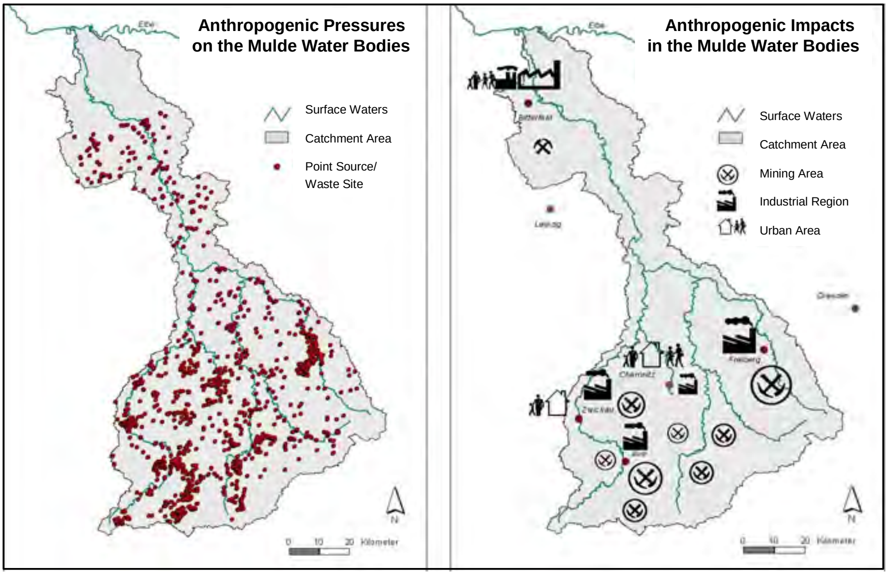

Fig. 2. Significant pressures on the Mulde river basin water bodies (after Beuge et al. 1999, Zweig et al. 2003).

Historically Contaminated Sediments and Soils in the Elbe River Catchment Area

Data from the Elbe River and its tributaries indicate, despite extensive improvement in water quality during the last 15 years, that the respective sediment situation of many priority pollutants has not reached an acceptable level. Historical pollution from sediments and soils becomes a significant source of contamination in Hamburg harbor, in the Elbe estuary, and in the coastal areas. Again, major deficiencies are in the assessment and prognosis of resuspension processes, and potential approaches to fill this gap are described from examples of the Elbe River.

The mines, tailings and sedimentation ponds of hard coal, metal and uranium mining along the Mulde River(s) present long-term pollutant sources. Both river basins show metal burdens above average. The elevated metal burden includes the typical ore metals Cd, Pb, Zn and U, mainly. The industrial areas provide essentially halogenated hydrocarbons, polycyclic aromatic hydrocarbons, phenols, cyanides and, to a lesser extent, metallic pollutants. Effluent seepage from tailings and mines show high metal and sulfate concentrations, which contribute to the contaminant transport in the nearby rivers. So, the united Mulde Rivers form the main path of metals into the Elbe River. Besides, one has to take in consideration, that an important part of the Mulde catchment covers landscapes with metallogenic origin, as the Ore Mountains (Schneider et. al. 2003a). The sediment contamination of the Mulde river was characterised by Beuge et al. 1999, see Table 1.

Table 2 compares several metals in the sediments (quarterly mean values from 1992 to 2003) of the Mulde catchment with averages in the earth crust and clay minerals (Beuge et al. 1989).
The highest sediment concentrations were investigated

- Freiberger Mulde: in the area of the mining and processing region Freiberg: As, Cd, Pb, Zn, Cu,
- Zwickauer Mulde: in the area of uranium mining and processing (Aue, Niederschlema, Hartenstein, Crossen): U, As
- United Mulde: in the area of the former industrial centre of Bitterfeld: Hg and organic compounds.

Hydraulic processes form the primary input factors for the large-scale dispersion of historical contaminated sediments. Unlike problems related to conventional polluted sites, the risks are primarily connected with the depositing of contaminated solids on soils in downstream regions. Therefore, sediment physical parameters and techniques form the basis for any risk assessment in this field. As floods frequently occur in the main river and its tributaries one has to take into account the impact of increasing discharge levels. Considering these facts sediment transport represents an important contaminant potential especially during floods. For example, table 3 shows the contaminant transport in flood sediments during the millenium flood 2002 in Saxony in the Elbe and the Mulde tributaries.

The importance of sediments as sinks for releases from many contaminant sources can be shown by data of reservoirs and other sediment sinks (e.g. see table 4). The owners of large sediment sinks, such as the big ports, mostly at the end

Table 1. Metals and arsenic in sediments of the Mulde tributaries (after Beuge et al. 1999).

I_{geo}-class (Müller 1979)	Heavily contaminated	Heavily to excessively contaminated	Excessively contaminated	Extremely contaminated
Freiberger Mulde	Cu			As, Pb, Zn, Cd
Zwickauer Mulde	Pb, Cu	As, Zn	U	Cd
United Mulde	U	Pb	As, Hg, Zn	Cd

Table 2. Comparison of metal pollutants in the sediments of the Mulde catchment (quarterly mean values 1992 to 2003) with average values of the earth crust [mg kg-1].

element	clark value	clay rock	Freiberger Mulde				Zwickauer Mulde				United Mulde
[mg/kg]	(Vinoradow)	(Turekian, Wedepohl)	Holzau	Muldenhütten	Obergruna	Mdg. Erlln	Schönheide	Niederschlema	Remse	Mdg. Sermuth	Bad Düben
As	2,0	7,0	260,0	285,3	1592,2	353,3	195,0	377,0	83,1	74,0	200,0
Cd	0,13	0,3	22,5	43,0	115,9	28,7	4,6	17,2	22,3	20,3	17,0
Co	18,0	19,0						100,0	57,0		
Cr	83,0	90,0	72,5	79,2	132,5	82,3	48,2	113,9	143,3	55,5	86,0
Cu	47,0	45,0	95,5	354,1	886,0	166,7	94,7	401,0	171,7	133,3	150,0
Ni	58,0	68,0	112,5	45,8	57,9	56,0	36,9	298,0	156,7	79,4	76,0
U	3,0	4,0					76,0	168,7	58,0		
Zn	200,0	95,0	1120,0	1990,0	5667,6	1533,3	339,8	1347,0	1633,3	1020,0	1000,0

of navigable rivers, are put at a disadvantage as they have to pay the expenses of all former, actual and future shortcomings in emission control within their entire catchment areas. Table 4 shows sediment data of the Glauchau reservoir, the Zwickauer Mulde upstream the Glauchau reservoir and the Freiberger Mulde.

In the Mulde catchment one has to consider, that radioactive compounds are drained off the mining waste heap sites in the catchment too and deposited in the sediment sinks. Considering the live time of radioactive compounds it becomes quite clear that the management of contaminated sediments will be a long term task. Table 5 shows sediment data of radioactive compounds in the Glauchau reservoir and the river upstream and downstream the reservoir.

Table 3. Contaminant transport in flood sediments of the millenium flood 2002 in Saxony in the Elbe and the Mulde tributaries, after Rank 2004 (S = sediments, R = riverside soils).

element	Elbe			Freiberger Mulde			Zwickauer Mulde		
[mg/kg]	samples S / R	median S	median R	samples S / R	median S	median R	samples S / R	median S	median R
As	40 / 605	22	20	59 / 105	480	118	27 / 27	95	92
Cd	26 / 568	2,0	0,74	57 / 98	9,3	1,7	26 / 21	3,6	3,2
Pb	26 / 568	96	54	57 / 98	803	300	26 / 21	89	96

Table 4. Metals and arsenic sediment data of the Glauchau reservoir, the Zwickauer Mulde upstream the Glauchau reservoir and the Freiberger Mulde (after Hoppe et al. 1994).

element	KLOKE natural background (mg/kg)	sediment data reservoir Glauchau (mg/kg), n = 18	sediment data Zwickauer Mulde upstream the Glauchau reservoir, (mg/kg), n = 21	sediment data Freiberger Mulde, (mg/kg), n = 27
Cd	3	6,9	4	100 – 1.600
Pb	100	105	2	812 – 18.000
Cu	100	181	10	150 – 4.500
Zn	300	445	50	1.360 – 34.000
Ni	50	53,8	10	40 - 350
As	100	55	154	50 – 1.600
Co	50	17	35	10 - 100

Table 5. Uranium and radium-226 data of the Glauchau reservoir and the river upstream and downstream the reservoir (after Ruhl, 1995).

	number of samples	uranium in dry residues			radium-226-activity		
		min	mean	max	min	mean	max
reservoir sediment (upper soil)	16	8 mg/kg	29 mg/kg	87 mg/kg	0,15 Bq/g	0,35 Bq/g	0,55 Bq/g
reservoir sediment (lower soil)	3	40 mg/kg	55 mg/kg	63 mg/kg	0,42 Bq/g	0,56 Bq/g	0,80 Bq/g
river upstream the reservoir	2	0,004 mg/l		0,005 mg/l	< 10 mBq/l		14 mBq/l
Zwickauer Mulde downstream the reservoir	12	0,007 mg/l		0,06 mg/l	40 mBq/l		160 mBq/l

Therefore, it is a matter of 'hydro solidarity' to achieve a full upstream/downstream integration of monitoring, stakeholder consultation, models and expert systems that can link basin pressures to transfers, across various administrative and/or political boundaries, and between the various land users, water users and other stakeholders. This could be practiced in a river basin-wide sediment assessment and management is needed.

Conclusions

A river basin-wide sediment assessment should, at first, perform inventories of interim depots with the catchment area, i.e. underground and surficial mining residues, river-dams, lock reservoirs and flood plain and groyne field sediments. Within a typical river section of 1 km length in the lower middle Elbe, the estimated nutrient and pollutant loads, deposited on the floodplains and in the river course, clearly demonstrate the specific sink function of both sites. At the same time, however, the results suggest, in contrast to the deposits in the floodplains, that sediments within the river course may partly be remobilized.

Detailed measurements for critical sites can apply the wider spectrum of laboratory and in-situ erosion stability tests. The study of erosion stability on sediment core profiles can be combined with analyses of the acid neutralizing capacity, providing a first indication on the heavy metal mobility in the grain matrix relative to the (bio-)chemical processes, which can form acidity. The flood plain profile from the Middle Elbe river exhibits a relatively high acid neutralizing capacity, and it can be expected that relocation processes involving oxidation of sulfide minerals will not induce long-term problems with respect to the mobility of heavy metals.

With respect to the latter date, already the first step – screening of all generic sources that can result in releases of priority substances and priority hazardous substances – will include the specific source/pathway 'historical pollution from sediment'. In practice, a catchment-wide assessment of historical contaminated soil and sediment should apply a three-step approach:

- Identification of substances of concern (s.o.c.) and their classification into 'hazard classes of compounds';
- identification of areas of concern (a.o.c.) and their classification into 'hazard classes of sites';
- identification of areas of risk (a.o.r.) and their assessment relative to each other with regard to the probability of polluting the sediments in the downstream reaches.

Outlook

Limited financial resources require a direction of investments to those sites with the highest efficiencies in risk reduction. Establishing a rough sediment dynamic model, building on tributary/main river dilution factors, sedimentation data, suspended particulate matter monitoring data as well as calculations of long-term costs and benefits, could be essential steps in a basin wide river management. This could include the use of 'soft' (geochemical and biological) techniques on contaminated soils and sediments, such as sub-aqueous depots, active capping, and application of natural attenuation processes (Beuge et al. 2002; Reincke et al. 2004). The problems discussed here are relevant also to other European countries. So the approach of a sediment management system considering seepage and disposal of waste from uranium tailings should be included in practical guidelines for the realisation of the WFD.

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